

# **Modeling and Measuring Fish Backscatter at Multiple Frequencies**

John K. Horne and J. Michael Jech<sup>1</sup>

Cooperative Institute for Limnology and Ecosystem Research, University of Michigan

NOAA Great Lakes Environmental Laboratory

2205 Commonwealth Blvd., Ann Arbor, MI 48105

Horne: (734) 741-2269, fax: (734) 741-2003; Jech (508) 495-2353, fax: (508) 495-2258

e-mail: [horne@glerl.noaa.gov](mailto:horne@glerl.noaa.gov)

e-mail: [j.jech@whsun1.wh.who.edu](mailto:j.jech@whsun1.wh.who.edu)

<sup>1</sup>Current Address: Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543

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## **LONG-TERM GOAL**

The long-term goals of the Principal Investigators are to quantify, understand and predict acoustic backscatter of fish.

## **OBJECTIVES**

Objectives of this project are to: quantify the sensitivity of theoretical backscatter models to the resolution of fish body and swimbladder digitized data; compare empirical measures of resonance backscatter to predicted amplitudes from theoretical backscatter models; examine and compare efficacy of multi-frequency and broadband sonars to discriminate targets; and to acoustically quantify size distributions, abundances, and behavior of fish.

## **APPROACH**

Acoustic backscatter models are based on digitized x-ray images of fish body and swimbladder morphology. Back-scatter amplitude as a function of acoustic wavelength, fish length, and fish aspect is estimated using Kirchhoff ray-mode scatter models<sup>1,2</sup>. Model predictions are used in computer simulations to estimate population abundances, and compared to empirical backscatter measurements from laboratory and *in situ* field measurements during mobile surveys.

## **WORK COMPLETED**

A manuscript examining the use of acoustic backscatter models when choosing sonar equipment and parameters was published in the Canadian Journal of Fisheries and Aquatic Sciences<sup>3</sup>.

Our examination of constraints in applying the inverse approach to size-based population abundance estimates using geometric scattering frequencies has been expanded and completed. A manuscript was submitted to the ICES Journal of marine Science<sup>4</sup>.

We organized and conducted a special session entitled, "Spatial Statistics in the Great Lakes - Quantifying Distribution Patterns" at the International Association of Great Lakes Research (IAGLR) annual meeting in Hamilton, Ont. The effects of choosing representative acoustic sizes on accuracy of fish population estimates was investigated using a series of computer simulations and

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initial results were presented at this session<sup>A</sup>. A manuscript has been submitted to the ICES Journal of marine Science<sup>5</sup>. We also organized and conducted the second annual Great Lakes Acoustic Workshop during the IAGLR conference. Approximately 50 participants examined the application of geostatistics to spatially- and temporally-indexed acoustic data.

We examined the sensitivity of Kirchhoff-ray mode backscatter models to resolution of digitized x-rays, and examined mean and variance in backscatter amplitude among fish species. Results were presented at the Acoustical Society of America meeting in Seattle, WA<sup>B,C</sup> and published in a proceedings volume<sup>6,7</sup>.

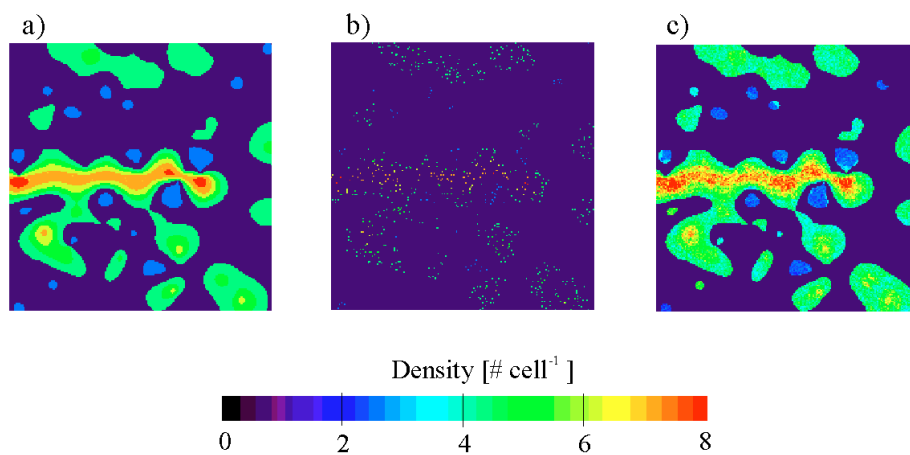
We conducted multi-frequency acoustic measurements of rainbow smelt and lake whitefish in Lake Michigan. Three different echosounder systems (Simrad 120 kHz splitbeam, BioSonics 420 kHz singlebeam, UW-Madison multifrequency (38, 50, 200 kHz) digital singlebeam) were coordinated to collect data. Whitefish and lake trout were x-rayed for backscatter modeling.

We are organizing a special session entitled, 'Theoretical and empirical innovations in fish and plankton acoustics,' at the joint American Society of Acoustics/European Acoustics Association conference scheduled for Berlin in March, 1999.

## RESULTS

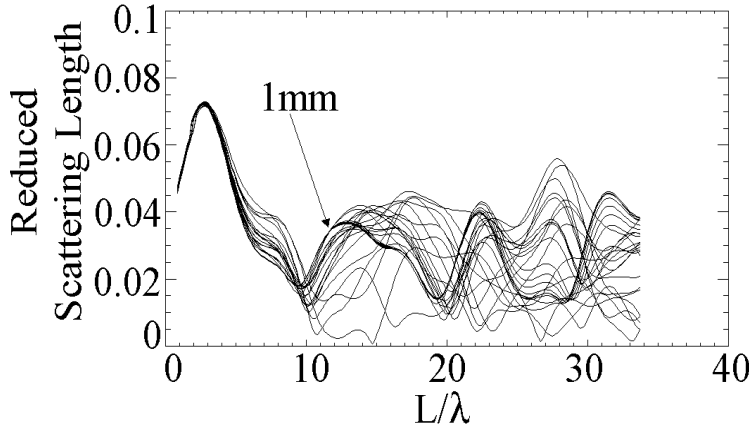
Caution must be used when combining the inverse approach with geometric scattering frequencies to estimate abundances of aquatic organisms. Although total abundance estimates were within <1% to 38% of population numbers, within length-class estimates were inconsistent among frequency combinations and across length-classes. Predictability of inverse simulations is non-linear when rather high frequencies (>10 kHz) are combined with non-monotonic backscatter models.

We simulated spatially random and spatially autocorrelated fish density and length distributions to examine the sensitivity of abundance estimates to organism distribution and choice of acoustic size, and to quantify variance in acoustic-based estimates of density, length, and abundance. Results from computer simulations show that it is difficult to estimate fish abundance and maintain an accurate length-frequency distribution. Among acoustic size estimation methods, a weighted-mean from a local search window provided optimal estimates of density, abundance, and length (Fig. 1).



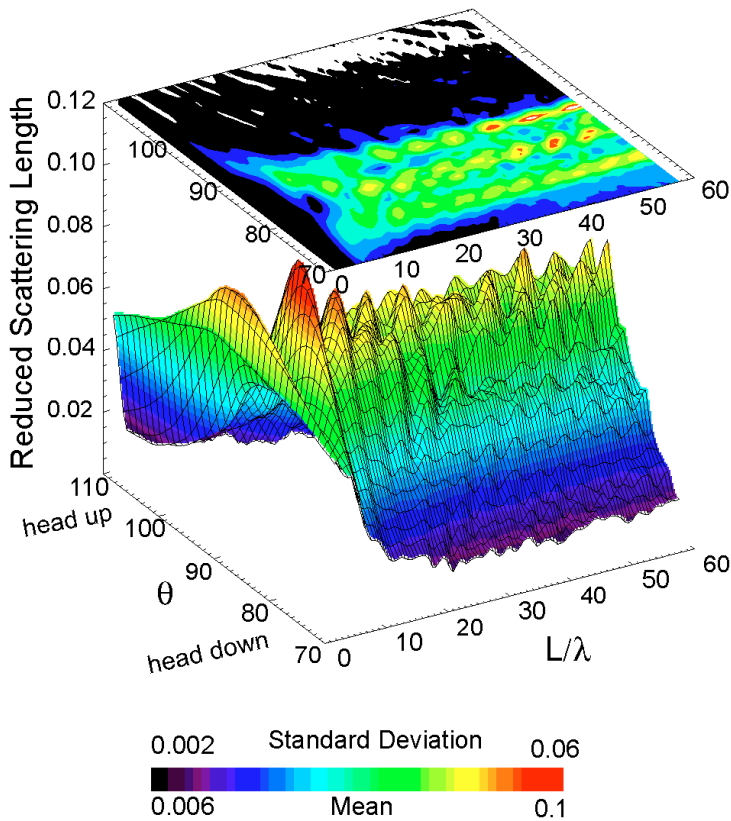
**Figure 1. Distribution of fish densities in acoustic size simulations. a) Original distribution of known population in patches and a single layer. b) Distribution of fish densities after random target removal of 95% of known individual fish targets. c) Distribution of fish densities estimated using a local window.**

Kirchhoff-ray mode (KRM) backscatter model predictions are sensitive to the resolution of digitized x-ray images. Backscatter amplitude curves diverge with decreasing resolution and increasing carrier frequency within the geometric scattering region (Fig. 2).



**Figure 2.** Twenty five predicted backscatter amplitude curves plotted as a function of the ratio of fish length  $L$  to acoustic wavelength  $\lambda$ . Reduced scattering lengths were predicted using the Kirchhoff-ray mode model of an Atlantic cod (*Gadus morhua*) at decreasing digitized resolutions of 1 mm to 31 mm.

The choice of carrier frequency combined with morphological and behavioral differences among organisms will also influence amplitudes and variability of backscattered echoes among fish species. Mean backscatter amplitude among conspecific fish is relatively constant at low fish length to frequency wavelength ratios (Fig. 3).



**Figure 3.** Mean (lower surface) and standard deviation (upper contour) backscatter amplitudes of nine Atlantic cod (*Gadus morhua*) plotted as a function of fish aspect  $\theta$  and the ratio of fish length  $L$  to acoustic wavelength  $\lambda$ . Reduced scattering lengths were predicted using the Kirchhoff-ray mode model. All fish were scaled to a length of 200 mm prior to calculations.

As fish length to wavelength ratios increase, echo amplitudes become more dependent on aspect, and variability in amplitude among individuals increases. Amplitudes peak when the swimbladder is perpendicular to the acoustic wavefront.

## **IMPACT/APPLICATIONS**

Morphologically-based backscatter models provide a convenient way to quantify the sensitivity of backscattered echo amplitudes to hardware parameters and organism behavior. We continue to quantify the relative importance of biological and physical factors on the magnitude and variability of acoustic backscatter. Theoretical backscatter models verified using *in situ* echo amplitude measures provide powerful tools to investigate aural reflective properties of aquatic organisms. Understanding sources of backscattered sound aids in the acoustic identification of aquatic organisms.

## **TRANSITIONS**

Our approach to model backscatter from fish using the KRM is now being used in a number of collaborative and independent projects. We have been consulted in modeling backscatter from salmon by researchers in Alaska (B. Adams, D. Burwen, V. Sonwalkar) and for examining flesh density at the Woods Hole Oceanographic Institute (D. Chu). The Alfred P. Sloan Foundation invited the PI's to a meeting on a census of the world's fishes and to a workshop on remote species identification. A manuscript reviewing acoustic species identification has been submitted to Reviews in Fish Biology and Fisheries<sup>8</sup>.

## **RELATED PROJECTS**

We are currently working on modeling backscatter from multi-chambered swimbladdered lavnun (*Acanthobrama terraesanctae*) in Lake Kinneret, Israel (with P. Walline), and from American and New Zealand eels (*Anguilla sp.*) (with J. Boubée, D. Dauble, and A. Haro). We have proposed extension of modeling backscatter from individual fish to modeling backscatter from fish aggregations.

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## **PUBLICATIONS**

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5. Jech, J.M. and J.K. Horne. Quantifying variability in acoustic estimates of fish abundance: effects of distribution, length, and acoustic size estimation. Submitted to the ICES Journal of marine Science.
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8. Horne, J.K. Acoustic approaches to remote species identification. Submitted to Reviews in Fish Biology and Fisheries.

## **PRESENTATIONS**

- A. Jech, J.M. and J.K. Horne. 1998. Quantifying variability in acoustic estimates of fish abundance: effects of distribution, length, and acoustic size estimation. International Association of Great Lakes Research (IAGLR) 41<sup>st</sup> Annual Meeting. Hamilton, Ontario, Canada, 18-22 May, 1998.
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